

Final Progress Report on
AFOSR F49620-~~02-0153~~

02-1-0153

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Objectives:

To develop computer vision algorithms based on biological, mathematical, and computational principles that are relevant to automatic target recognition, especially as this pertains to the Air Force.

Status of Effort

The effort proceeded actively for three years, with progress as summarized below. Researchers at Wright-Patterson Air Force Base have become interested in the material, and have done internal experiments to check its applicability to ATR. Unfortunately funding for the project has terminated precisely when transitions are ready to take place.

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Accomplishments/New Findings

The research during the past year continued in two main directions relevant to target recognition. First, in early vision we developed a completely general approach to inferring scene structure from the analysis of different flow patterns. In one dimension these flows correspond to edge completions (when embedded in the image) or stereo (when data from two images are fused into 3-D space curves); in two dimensions we have characterized texture, shading, and color flows. We have also addressed through geometric modeling the interactions between edge, shading, color, and texture elements as a function of their orientation, and our research in stereo is evolving from curve-based stereo algorithms to surface algorithms. We have been able to demonstrate that rich descriptions of scene structure can be inferred from these flows, and their interactions. For example, attached shadow boundaries can be separated from object boundaries by examining both the boundary and shading flow interactions, and the shading and hue flow interactions. Previously such problems were thought to be high-level and abstract from early vision. Their role in defining features for model-based ATR and object recognition is clear.

Furthermore, we remark in passing that this research is having a significant impact in theoretical neuroscience, because (i) it explains the function of long-range horizontal connections in visual cortex and (ii) it greatly elaborates the range of tasks that the first visual area in primate cortex could accomplish.

The second major direction for research is more abstract, and relates to building a general approach for machine learning of visual patterns. Again our ideas are geometric, but this time they relate to the mathematical question of finding the proper subspace of (possibly very high-dimensional) non-linear measurement spaces. Our technique not only finds such subspaces according to the principles of harmonic analysis, but does so for data that is non-uniformly distributed. Most importantly, it results in sub-spaces that are Euclidean in structure, so that clustering and other decision-making techniques can be applied. Much progress has been made on the computational techniques, in effect introducing a new form of non-linear PCA. Many applications of these new techniques are developing, from image analysis to semantic indexing.

In summary of the three years of this project, we have made significant progress in identifying the types of structural information that can be used in ATR; we have developed a series of algorithms for extracting it; and we have connected with researchers in AFRL to transition it. We very much feel this project has been a success.

Personnel Supported

- Professor Steven W. Zucker
- Mr. Patrick Huggins
- Mr. Ohad ben Shahar
- Mr. Gang Li

Publications

Note: Publications are only listed for the final year of the project. Publications from previous years are available from the annual reports.

1. Ben-Shahar, O., Huggins, P.S., Izo, T., and Zucker, S.W., Cortical Connections and Early Visual Function: Intra- and Inter-Columnar Processing, *J. Physiol.(Paris)*, 2003, **97**(2,3), 191 - 208.
2. Ben-Shahar, and Zucker, S.W., The Perceptual Organization of Texture Flow: A Contextual Inference Approach, *IEEE Trans. Pattern Analysis and Machine Intelligence*, 2003, **25**(4), 401 - 417.
3. August, J., and Zucker, S.W., Sketches with curvature: The curve indicator random field and Markov processes, *IEEE Trans. Pattern Analysis and Machine Intelligence*, 2003, **25**(4), 387 - 401.
4. Pizer, S., Damon, J., Siddiqi, K., Szekely, G., and Zucker, S.W., Multiscale Medial Loci and Their Properties, *Int. J. of Computer Vision*, **55**(3), 2003, 155-179.
5. Ben-Shahar, and Zucker, S.W., Sensitivity to curvatures in orientation-based texture segmentation, *Vision Research*, 2004, **44**(3), 257 - 277.
6. Ben-Shahar, and Zucker, S.W., Geometrical computations explain projection patterns of long-range horizontal connections in visual cortex, *Neural Computation*, 2003, **16**(3), 445 - 476.
7. Ben-Shahar, and Zucker, S.W., Hue geometry and horizontal connections, *Neural Networks*, 2004, in press.
8. Ben-Shahar, O., and Zucker, S.W., Hue fields and color curvatures: A perceptual organization approach to color image denoising, *Proc. IEEE Conf. on Computer Vision and Pattern Recognition, CVPR 03*, Madison, WI, June 2003.
9. Li, G., and Zucker, S.W., A differential geometric approach to stereo correspondence, *Proc. 2nd IEEE Workshop on Variational, Geometric, and Level Set Methods in Computer Vision (VLSM 2003)*, Nice, 11-12 October 2003.

10. Zucker, S.W., Computing in Cortical Columns: Information Processing in Visual Cortex, in **SENSORS AND SENSING IN BIOLOGY AND ENGINEERING**, F. Barth, J. Humphrey, and T. Newcomb (eds.), Springer-Verlag, Wien, 2003, 263 - 274.

Interactions

- Researchers in ATR from Wright Patterson AFB and AFRL have shown interest in our biological models and our non-linear PCA. They visited Yale on 25 Feb 2004. Interactions are continuing.
Contact: Dr. D. Gregory Arnold, AFRL/SNAT, Bldg 620 Gregory.Arnold@wpafb.af.mil
- The texture flow research directly supported by AFOSR has led to a color (specifically hue) flow model that is of interest to Adobe for their Photoshop system.
- Participation with FMAH Corp. and Plainsight Systems on Integrated Sensors and Processing using neurophysiologically-inspired computer vision and dimensional analysis.
Contact: Dr. Ronald Coifman (COIFMAN@FMAH.COM).

Participation at Meetings

- Keynote Speaker, *3DPTV*, Thessaloniki, September, 2004.
- Invited Speaker, *Workshop on Neo-Gestalt Contributions to the Understanding of Perceptual Organization*, International Congress of Psychology, Beijing, August, 2004.
- Invited Lecturer, *Workshop on Computational Neuroscience*, Telluride, July 2004.
- Invited Speaker, *Mathematical Models of Visual Perception*, Accademia delle Scienze of Bologna, Italy, 1 July, 2004.
- Invited Speaker, *The Depictive Space of Perception*, Mitteleuropa Foundation, Bolzano, Italy, June 7-9, 2004.
- Invited Participant, ARO/Fitzpatrick Center ATR meeting, Duke University, 2-4 December 2003.
- Invited Participant, DARPA IPTO meeting, 12-13 November 2003.
- Distinguished Lecturer, Department of Computer Science, University of Alberta, 6 Nov 2003.

- Invited Speaker, *2nd IEEE Workshop on Variational, Geometric, and Level Set Methods in Computer Vision (VLSM 2003)*, Nice, 11-12 October 2003.
- Invited Speaker, *European Conference on Visual Perception*, Paris, Sept 2003.

Consultative and Advisory Functions

- Editorial Board, Computational Imaging and Vision, Kluwer academic publishers.
- Editorial Board, International Journal of Computer Vision, Kluwer.
- Editorial Board, Journal of Mathematical Imaging and Vision, Kluwer academic publishers.
- Editorial Board, Neural Computation, MIT Press.
- Editorial Board, Neural Networks.
- Associate Editor, Spatial Vision, VNU Science Press.

Transitions

We estimate that more than 2000 copies of our logical/linear system have been requested by anonymous ftp.

See also the *Interactions* listed above.

New Discoveries, inventions, or patent disclosures

None

Honors/Awards

- David and Lucile Packard Professor of Computer Science and Electrical Engineering, Yale University, 1998.
- (By)Fellow, Churchill College, Cambridge.
- Fellow, Canadian Institute for Advanced Research.
- Fellow, Institute of Electrical and Electronic Engineers (IEEE).
- SERC Fellow, Newton Institute for Mathematical Sciences, University of Cambridge.

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